NASA Human Spaceflight Scenarios Do All Our Models Still Say 'No'?

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Context

1. Commercial & Cost Data
   Tomorrow – Sept. 13, Space Cost and Economics, 10am-12:30pm

   "An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions"

2. Estimating Costs for New Elements from Data
   Earlier – Sept. 12, Reinventing Space II, 3:30-6:30pm

   "The Opportunity in Commercial Approaches for Future NASA Deep Space Exploration Elements"

3. Exploration Scenarios
   Here – Sept. 12, Space Exploration, 7:30-9pm

   "NASA Human Spaceflight Scenarios Do All Our Models Still Say 'No'?"

Data

↓

Estimates

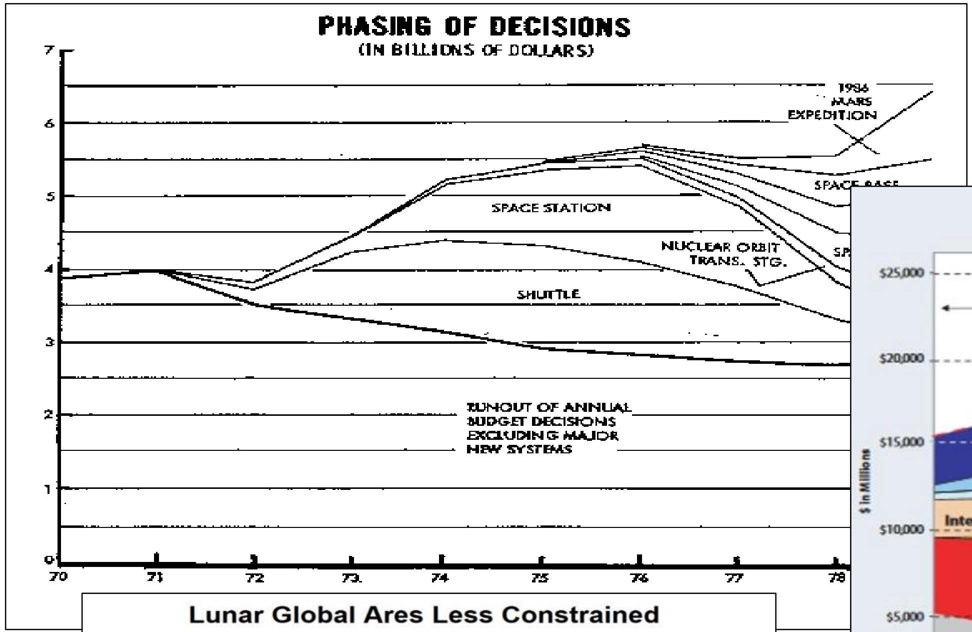
↓

Architectures

“All our models say ‘no,’ even models that have generous affordability considerations.”

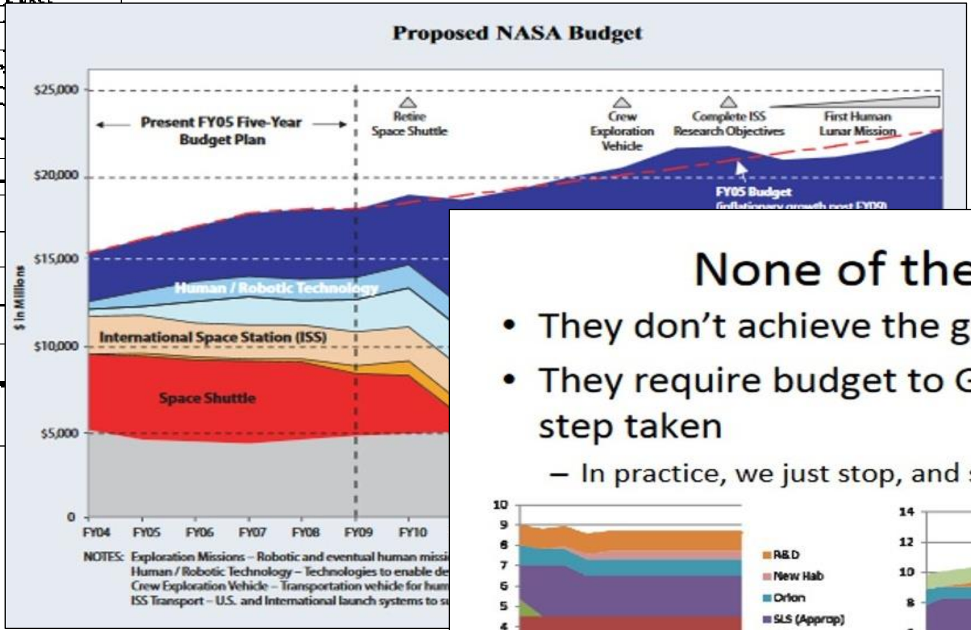
Elizabeth Robinson, NASA’s chief financial officer, 2011, *The New York Times*

A Brief History of NASA Life Cycle Cost Analysis

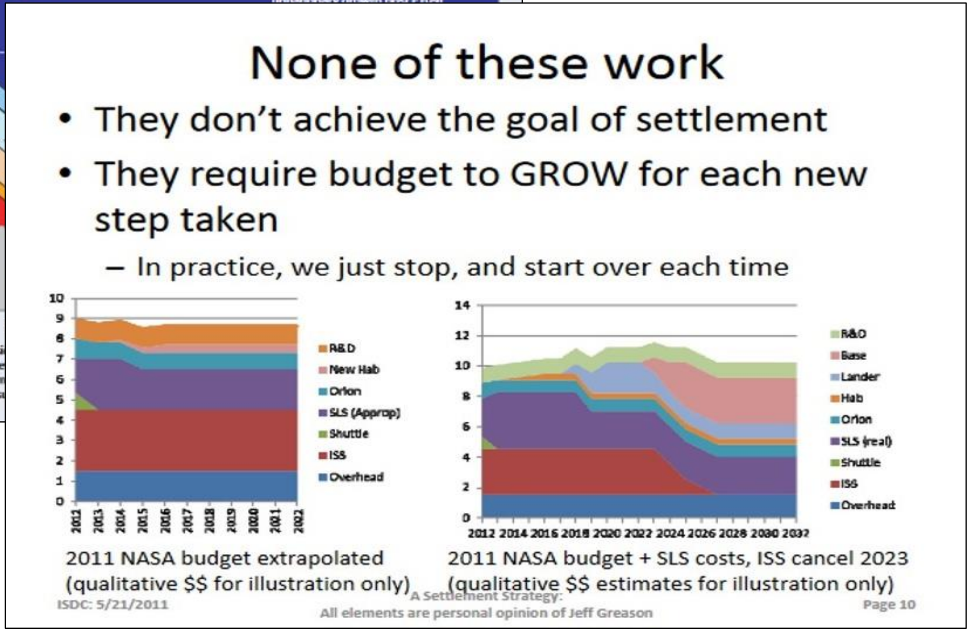


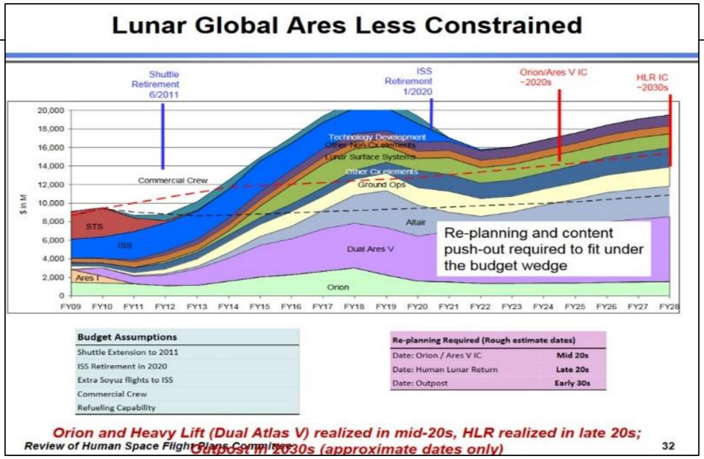
1969 Space Task Group

2004 Aldridge



2011 Greason





2009 Augustine

A Brief History of NASA Life Cycle Cost Analysis

Most recently, LCC analysis has been avoided

- Constellation canceled (it's own sand-charts used to show ≠ add up)
- Avoid "*sticker shock*"
- Long term uncertainty, LCC analysis perceived as unproductive
- "Capability Driven Framework" as substitute

Is the cure worse than the disease?

Neglecting to look long term with life cycle cost analysis "*does not provide the transparency necessary to assess long-term affordability*"; difficult to understand if NASA "*is progressing in a cost-effective and affordable manner*."

-GAO 2014

A Brief History of NASA Life Cycle Cost Analysis

The usual suspects – 5 (poor?) assumptions repeat

1. Budgets grow at a rate not supported by historical data while costs (inflation) increase at a rate equal to assumed budget growth
   - Aerospace cost *inflation as an assumption, not an estimate
2. System annual ops always much less than annual development
3. 100% of funds from some programs end is available to another beginning
4. Funds easily moved around
   - NASA Human space exploration & operations is the priority
5. Optimism – new programs are always different – especially useful when past data points are so expensive they would never yield attractive new data points *without optimism*

**...or what passes for vague notions about cost inflation in aerospace*

Method

Lets turn the usual assumptions on their head

- Go with history in assumptions
- Go with reference data in cost estimates
- Assume life cycle cost analysis can be productive and useful to many stakeholders

Method

The opposite of the 5 usual suspects

1. Budgets increase at their historical rate – 1.95% a year (since 2003)
   - Cost inflation from NASA New Start Inflation Indices, 2.5% a year
2. Historically, annual ops budgets about the same as in earlier development
3. Historically, ample doses of skepticism and rigorous assessment are justified around the notion funds from a program ending become wholly available to another starting
4. Avoid moving money around and across accounts, or making assumptions one area remains flat while another grows much faster
   - Historically, creates the issue of making everyone who loses funds the enemy of the project receiving funds, undermining the kind of support needed to sustain the new program
5. Let historical reference data speak for itself – bad *and* good.
   - Avoid fudge factors for optimism ("factor for management challenges", etc.)

Method – What data? What estimates?

Data

- Tomorrow – Sept. 13, Space Cost and Economics, 10am-12:30pm

"An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions"

Estimation

- Earlier – Sept. 12, Reinventing Space II, 3:30-6:30pm

"The Opportunity in Commercial Approaches for Future NASA Deep Space Exploration Elements"

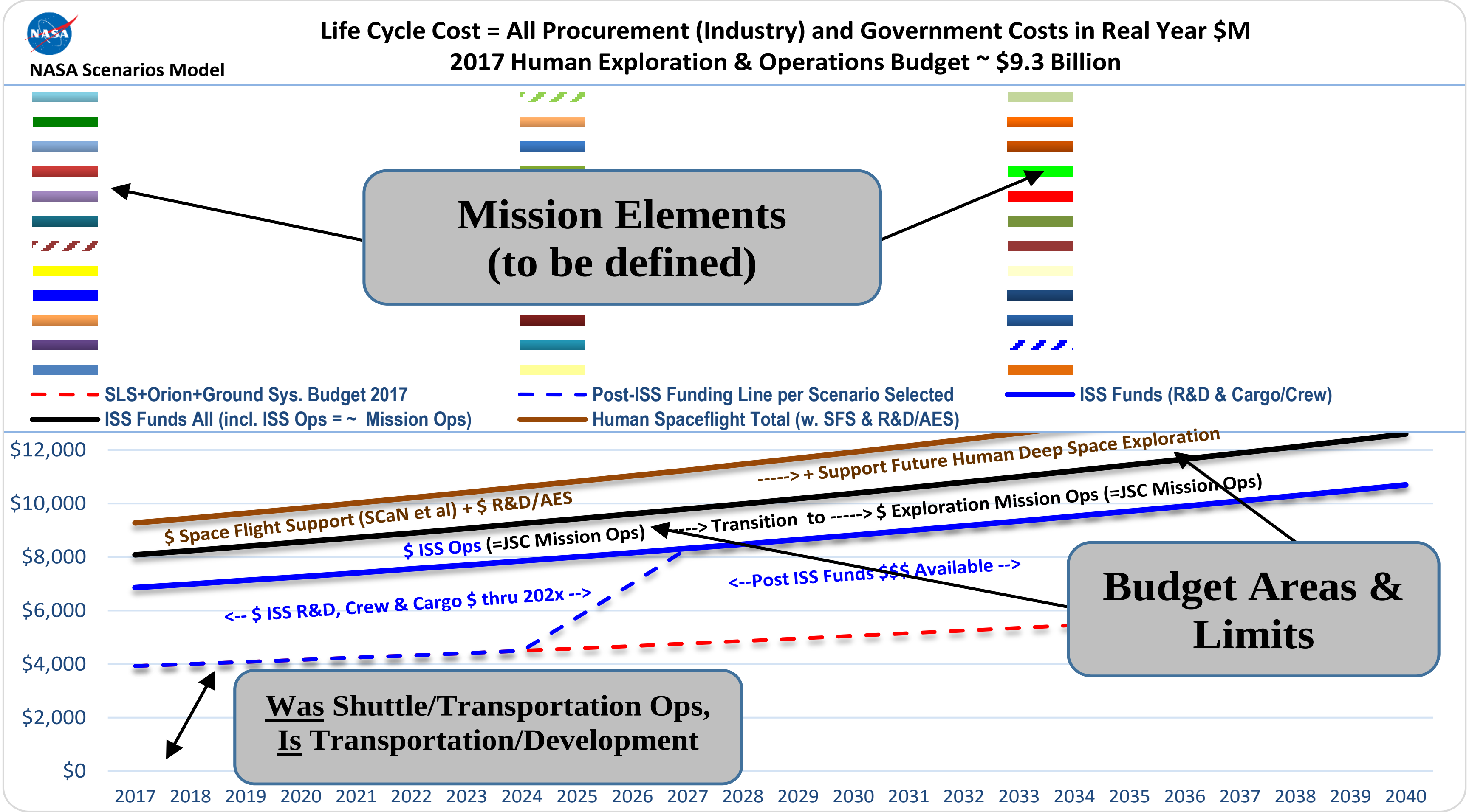
Method

The views expressed in this analysis are those of the author(s) and do not reflect the official policy or position of the US Government or NASA.

The analysis that follows explores the life cycle cost of many scenarios, choosing none, to understand these relative to each other, using results to <u>understand a variety of fundamental questions</u>.

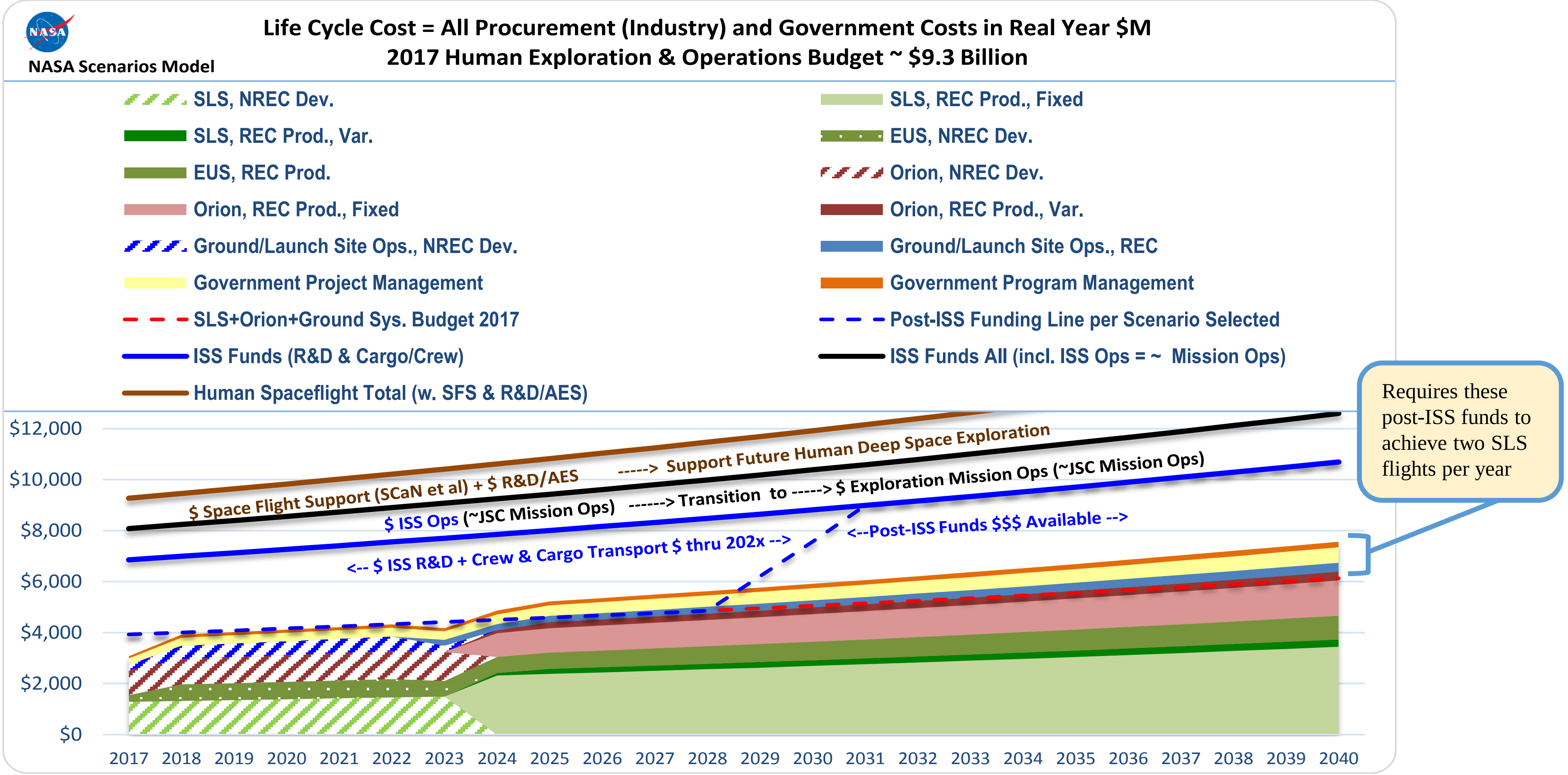
Forget answers a moment, lets go back to questions

Method – A Blank Cost/Budget Template



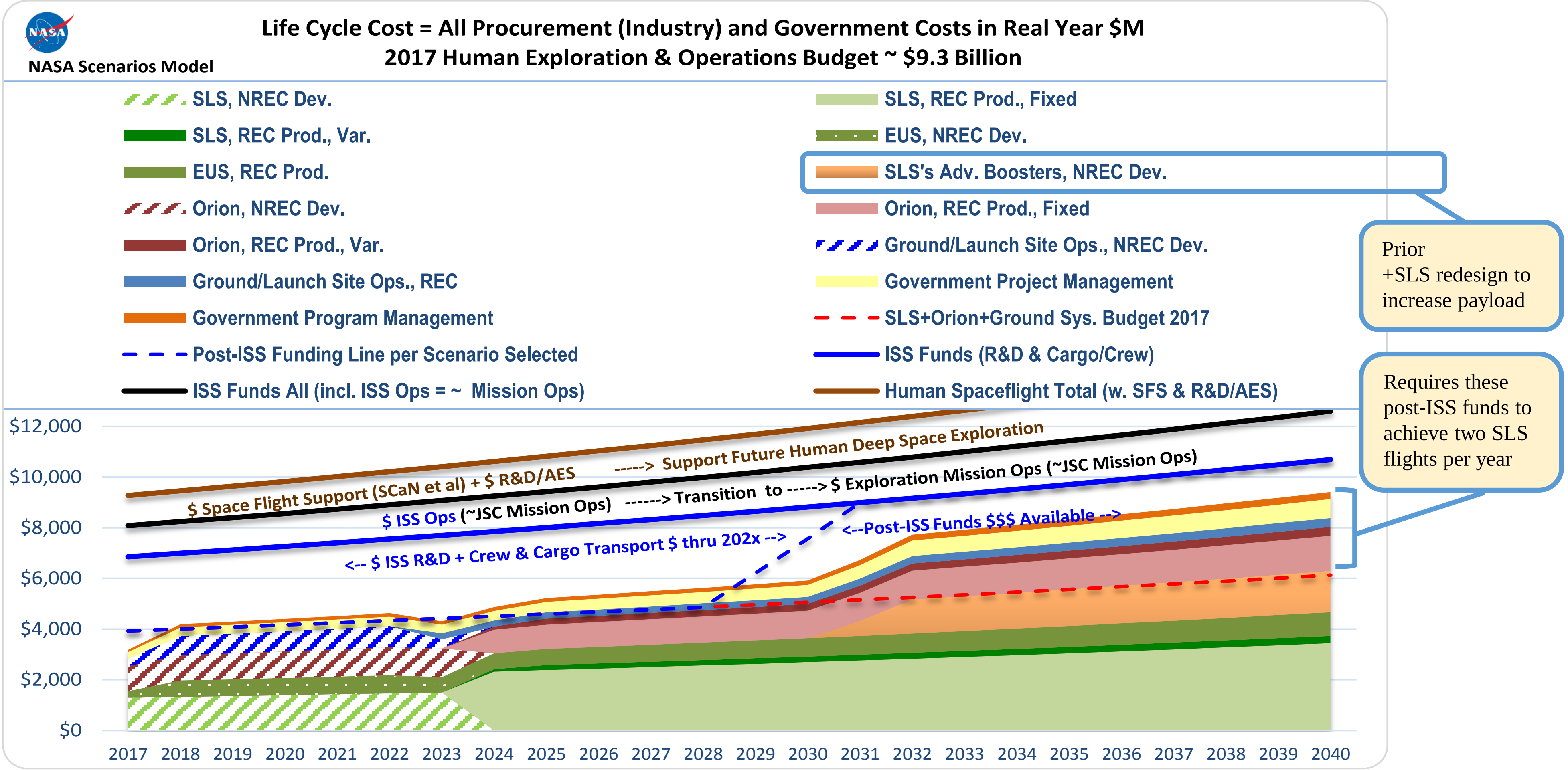
1. **Combine what is certain enough with an understanding of budget areas**
2. **See what remains & what's possible**

The Baseline Scenario



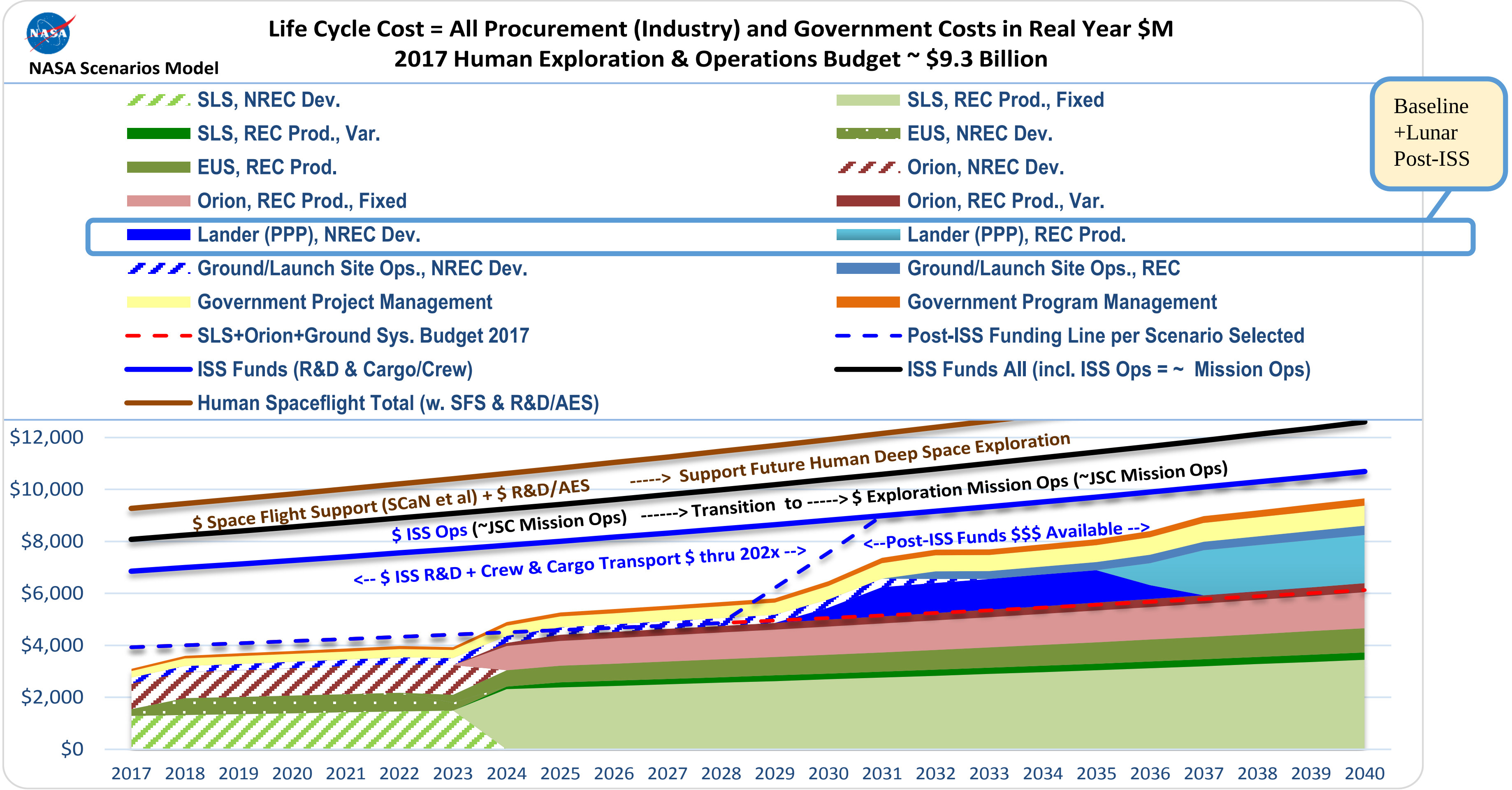
The Baseline Scenario, SLS / EUS and an Orion (every other launch). Productivity / benefit is = two launches of the SLS and one launch of Orion per year beginning in 2024. Payloads could be funded from post-ISS funds, in this scenario the white-space opening up after 2024 (←Post ISS Funds $$$ Available→). If the ISS continues until 2028, the transition line moves to the right, with a need to lower the SLS / Orion flight rate below 2 a year through that date or find other cost reductions to remain below the dashed (------) available budget line.

The Baseline Scenario + Upgrades → 130t Payload to LEO



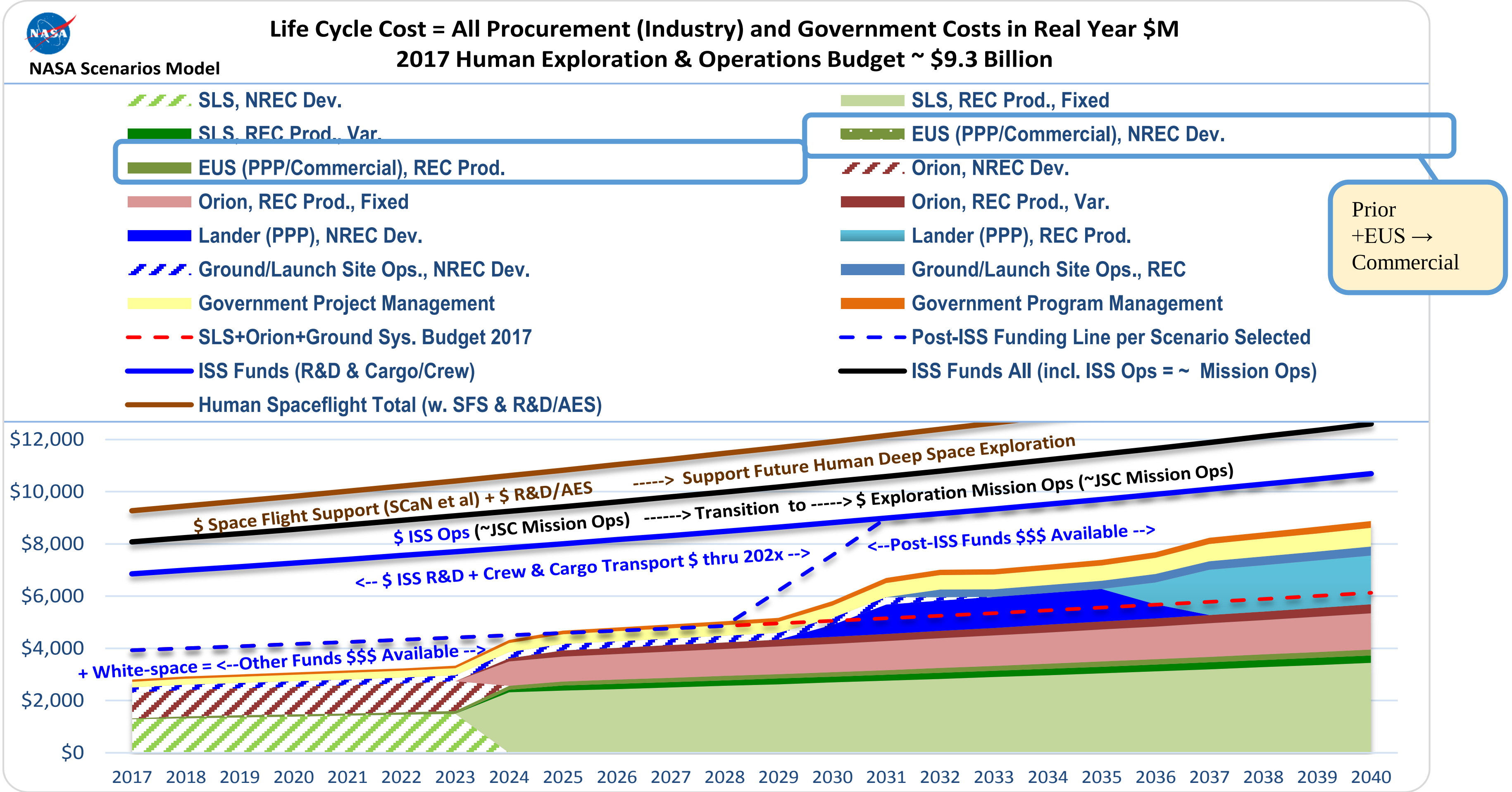
This is the same as the prior Baseline Scenario, except beginning an advanced / evolved booster development project after the end of the ISS to reach the congressionally mandated SLS 130t payload capability. This is also a capability required in the NASA Mars Design Reference Mission (DRM). The scale of the potential yearly cost for an advanced / evolved booster development, in parallel to ongoing operations of the SLS, to take the SLS to a 130t payload capability (to LEO) is put here on a par with the original SLS annual development costs. This is in consideration of the potential extent and scale of new advanced / evolved boosters, similarly on a par with the SLS experience to date. It's assumed the advanced / evolved booster is acquired with contractual approaches similar to past SLS approaches (partnerships, or partnerships and reusable advanced / evolved SLS boosters, are not considered here.)

The Baseline Scenario + [Lunar Lander] (as Partnership)



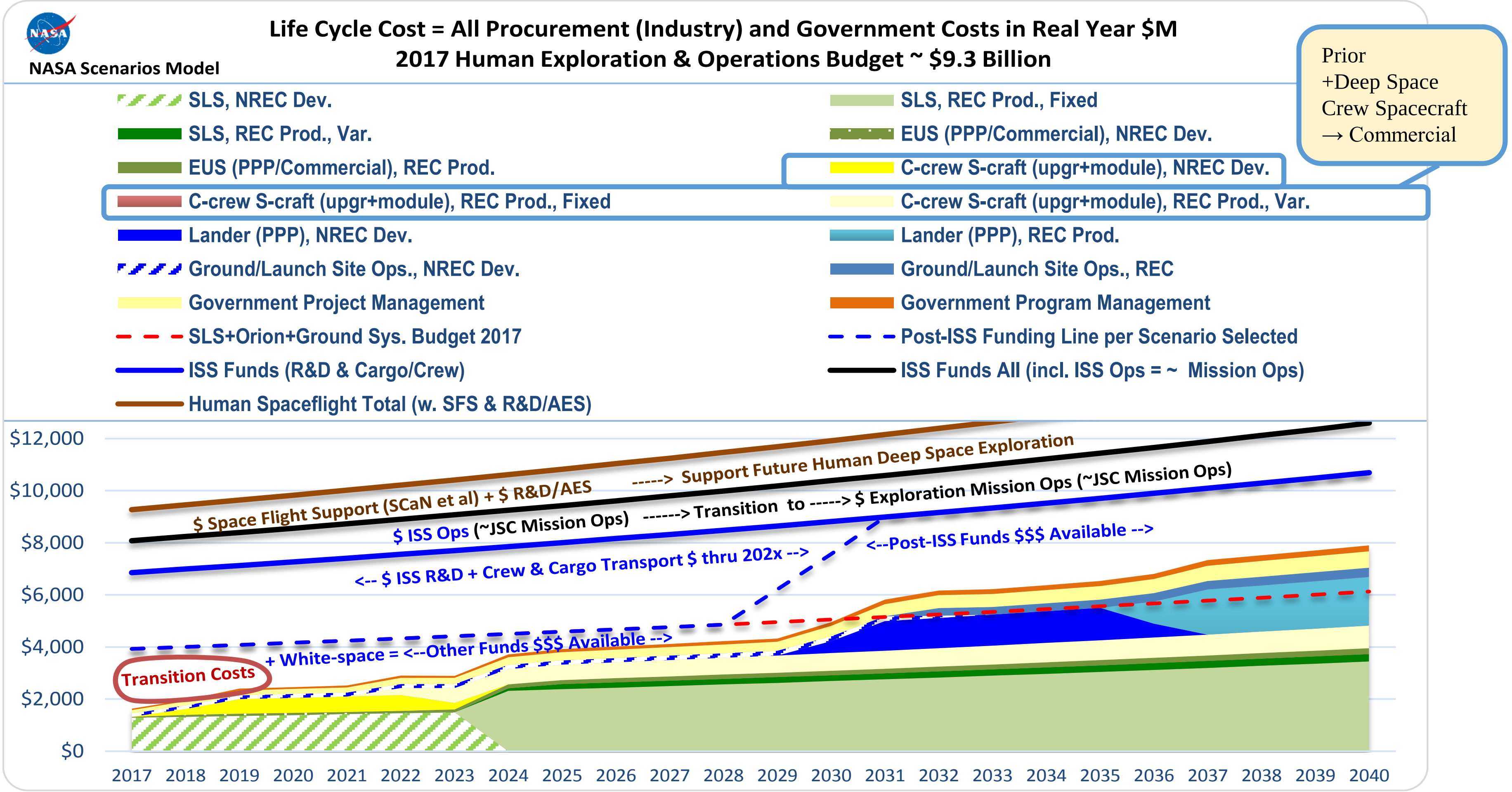
A Return to the Moon in 2037. In this scenario, an alternating SLS/Orion/lander tempo allows for a return to the Moon after completing a commercial lunar lander development. The nearer term SLS / EUS payload capability is adequate to achieve this type of scenario. Crewed lunar missions would occur once per year starting in 2037. As with previous scenarios, costs exceed budgets in the years before the end of the ISS indicating a need to reduce the flight rate before the end of ISS or find other cost reductions so these remain below the dashed (------) available budget lines.

The Baseline Scenario + [Lunar Lander + EUS] (as Partnership)



This is the same as the prior scenario, except the EUS is a public private partnership rather than a cost-plus/sole source contract. This leaves room to grow in the near term, assuming the same annual budget levels as would have been available for a cost-plus/sole-source effort. There is also some room to grow in the far term, the white-space unassigned after 2028 (←Post ISS Funds $$$ Available→).

The Baseline Scenario + [Lunar Lander + EUS + Deep Space Spacecraft] (as Partnership)

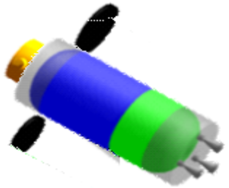


This is the same as the prior scenario, except here the deep space spacecraft is also a public private partnership. The new partnerships build off the knowledge gained in the Orion program and are open to existing US space industry partners in cargo or crew, the current Orion partners, or new partners. The basis of estimate for the costs of a commercial deep space spacecraft builds off the existing US commercial crew program.

Natural Trade-space Continuation → Commercial Heavy & Refuel

Lunar Propellant LO2/LH2 Depot/CPS

DRM 33C Depot LOX/LH2



Propellants	LOX/LH2
Stage Diameter	6 m
Stage Length	16 m
Oxidizer Boiloff	0%/month
Fuel Boiloff	0.5%/month
Sub-orbital T/W	0.72
Orbital T/W	0.15
Power	2625 W
Cryocooler Power	1625 W
Mass Growth, %	30
# Engines / Type	3 RL10 B-2
Engine Isp (100%)	464 sec

	Mass, kg
2. Body Structure	5,213
3. Induced Environmental Protection	319
5. Main Propulsion	852
6. Orient Control Separation	140
7. Prime Power	137
8. Power Conversion and Distribution	27
9. Guidance and Navigation	38
10. Instrumention	32
11. Communication	97
12. Thermal Control	1,521
16. Range Safety and Abort	69
16a. Mass Growth Allowance	2,539
19. Ordanance	20
Dry Mass	11,002
21. Residual Propellant	2,115
23. Inflight Losses	14
25a. RCS Propellant	5,209
25. Total Propellant inc Boiloff	105,767
IMLEO	179,813

Propellant Burn 1	102,917
Payload Burn 1	55,706
DeltaV Burn 1	3,973

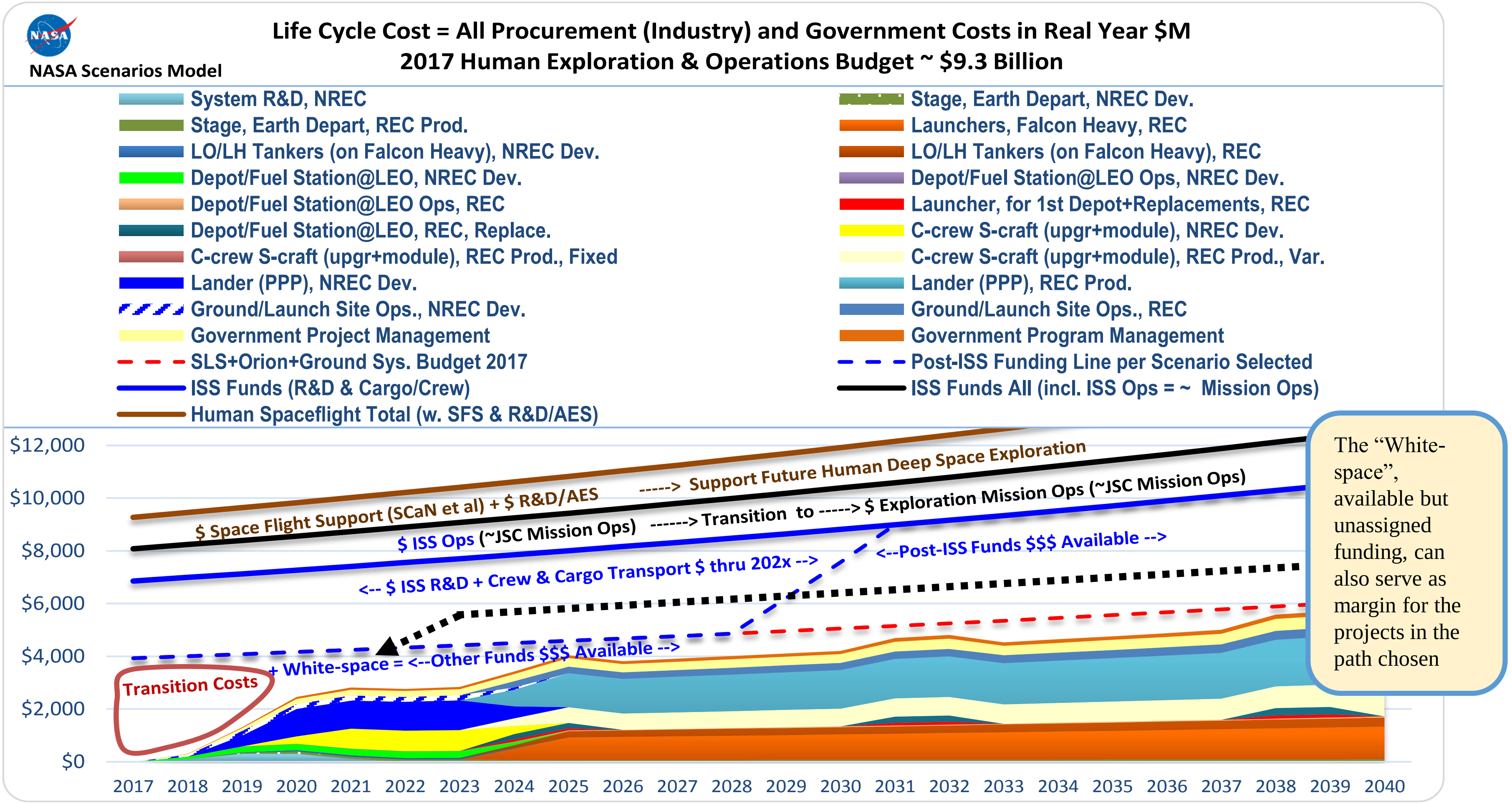
Description:

The combined propellant depot and CPS stage is capable of holding enough O2 and H2 (100MT) to perform Lunar missions requiring up to 4 km/s of delta-V when used as a CPS stage. Both the Depot and CPS have MLI (SOFI for ground hold and 60 layer MLI), cryocoolers, and sunshield. Power is with Ultraflex solar cells.

Both the Depot and Depot-Derived CPS can be launched from a Falcon Heavy or Delta IV Heavy replacing the second stage of the launch vehicle and using the RL 10 engines to place itself into a 407 km, 28.5 deg inclination circular orbit.

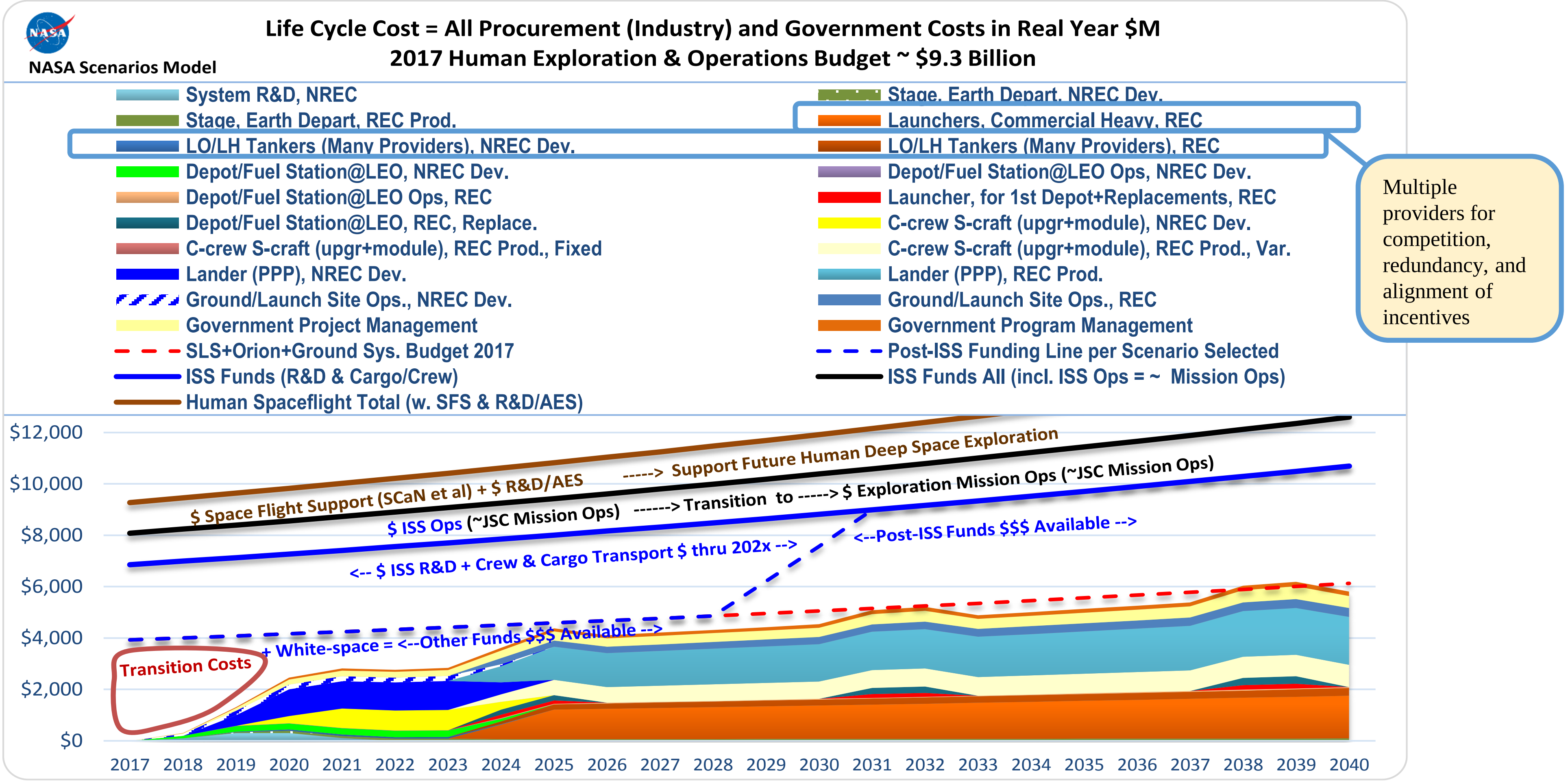
The combined propellant depot and chemical propulsion stage is capable of holding enough O2 and H2 (100MT) to perform lunar missions requiring up to 4km/s of delta-v when used as a propulsion stage. From the 2011 NASA Propellant Depot Study / Courtesy Alan Wilhite.

Lunar via Single Commercial Heavy Lift & Refueling w. a Depot



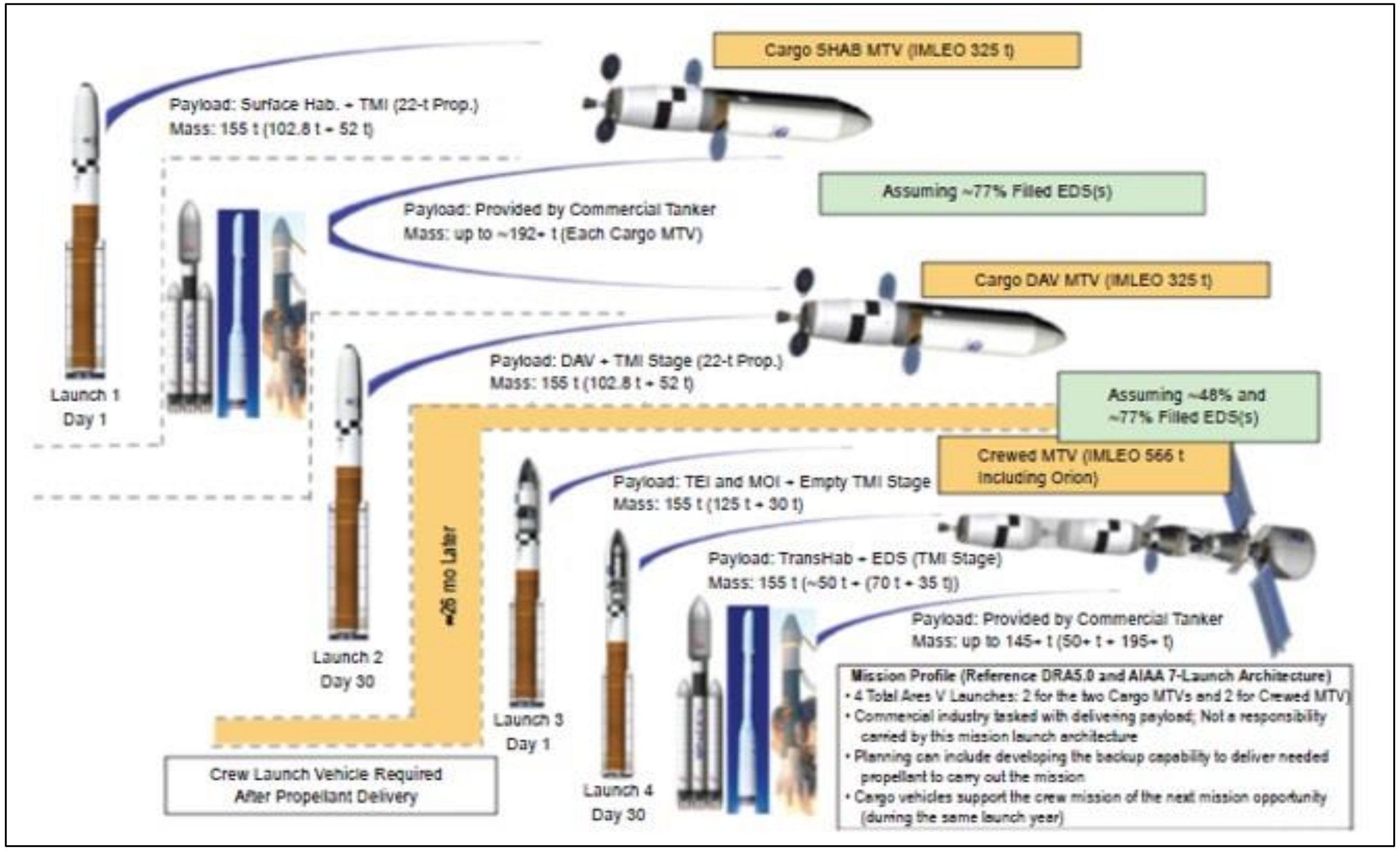
A return to the Moon scenario using commercial / public private partnerships, a propellant depot, and reliant on the SpaceX Falcon Heavy launch vehicle. Productivity / benefit is = a lunar landing in 2025 and an operational capability to repeat these lunar missions at a pace of one a year.

Lunar via Multiple Commercial Heavy Lift & Refueling w. a Depot



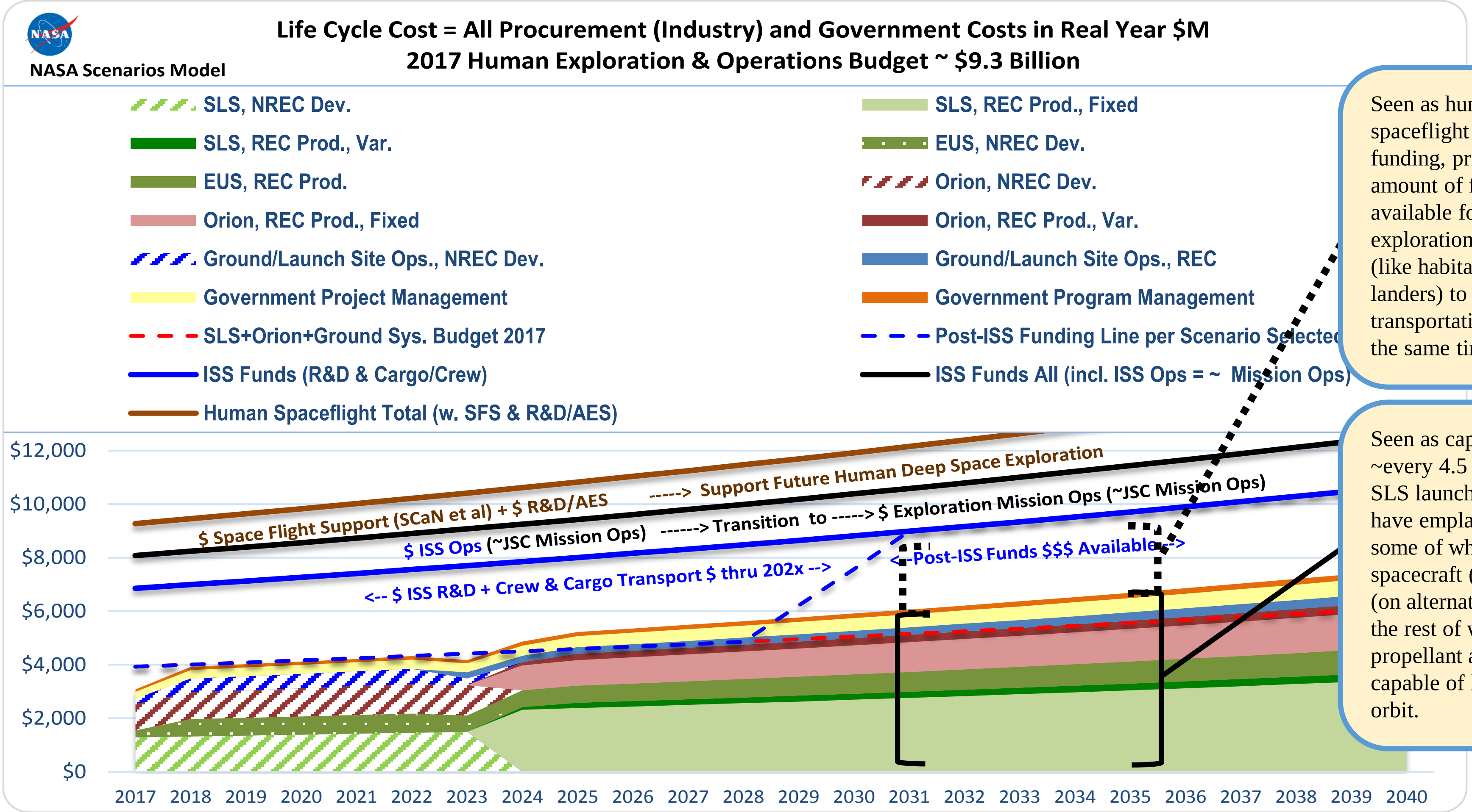
A return to the Moon scenario using commercial / public private partnerships, a propellant depot, and multiple competing commercial launch and propellant providers, of which at least one is in the 50t to LEO payload range. Propellant available at the depot is paid for by a customer (NASA) at ~ $7,000 per kg (in 2017 $). The productivity / benefit is a lunar landing in 2025 and an operational capability to repeat these lunar landing at a pace of one a year. Different business case models might apply, with NASA at one extreme collaborating with individual elements in different business arrangements, launchers, propellant tankers (or both), propellant at the depot, or for development and operation of the depot, versus another extreme where NASA pays for propellant at the very end, when a stage arrives for refueling services.

Natural Trade-space Continuation → Baseline + Refuel + Farther



A "Commercially delivered propellant option (EDS tanker derivative)" from the 2010 NASA review of its Mars design reference mission (DRM).

The Baseline Scenario Viewed as CAPABILITY → 1,000t

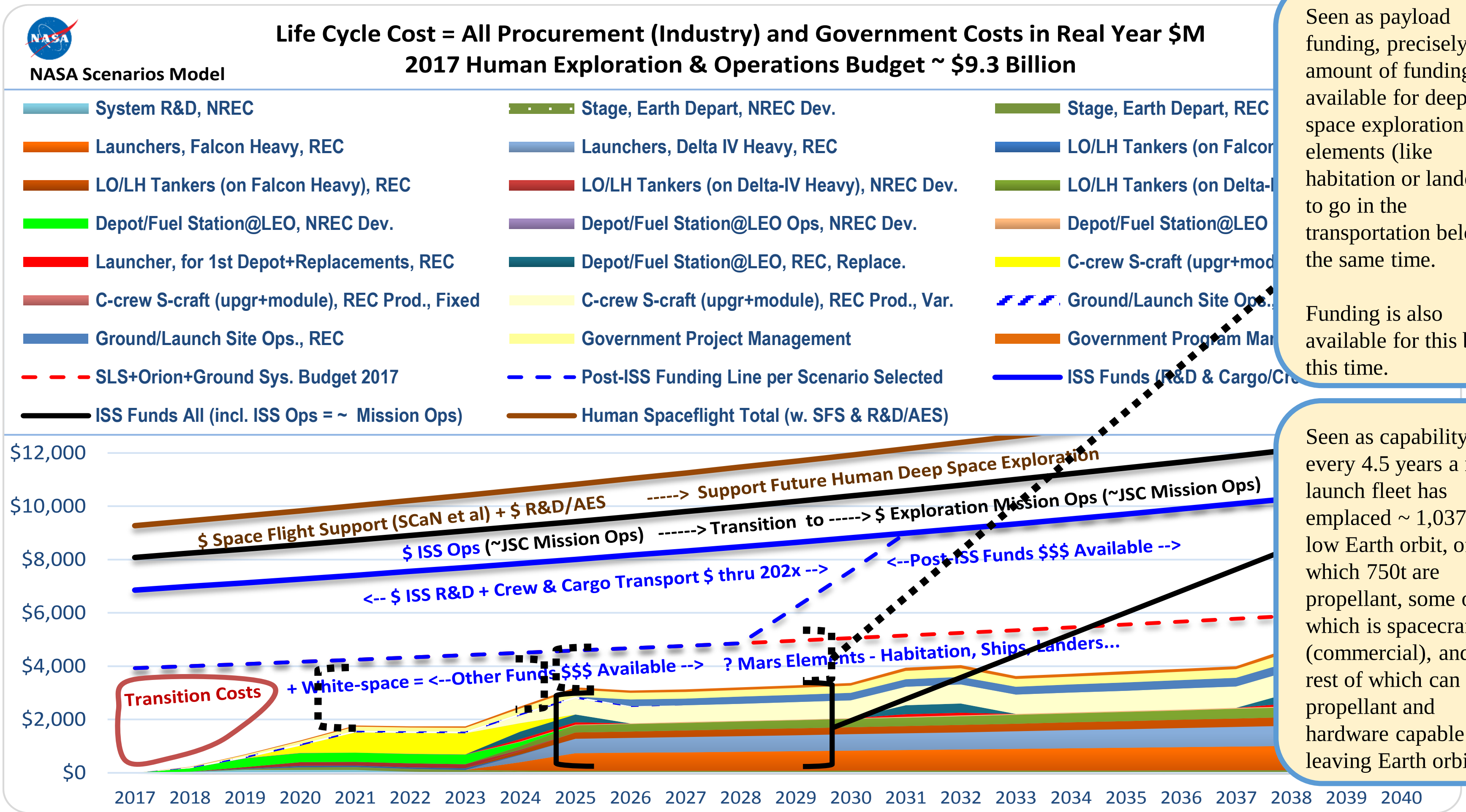


Seen as human spaceflight payload funding, precisely this amount of funding is available for deep space exploration elements (like habitation or landers) to go in the transportation below in the same time.

Seen as capability, ~every 4.5 years the two SLS launches a year have emplaced ~1,000t, some of which is spacecraft (Orion) mass (on alternate flights) and the rest of which can be propellant and hardware capable of leaving Earth orbit.

The baseline scenario seen as a capability for deep space exploration. The connection between any transportation capability and payloads as specific exploration elements (for example, habitation or landers) is apparent when looking at the whole as tonnage emplaced over any time by any supporting transportation system. The means, the supporting transportation system, and the ends, exploration elements leaving for deep space are by necessity fiscally linked. This scenario emplaces ~1,000t (metric tons) into low Earth orbit every 4.5 years, some of which is crew spacecraft, in this case Orion (4.5 times).

Commercial Heavy Lift & Refuel Viewed as CAPABILITY → 1,000t



Seen as payload funding, precisely this amount of funding is available for deep space exploration elements (like habitation or landers) to go in the transportation below in the same time.

Funding is also available for this before this time.

Seen as capability, ~ every 4.5 years a mixed launch fleet has emplaced ~ 1,037t into low Earth orbit, of which 750t are propellant, some of which is spacecraft (commercial), and the rest of which can be propellant and hardware capable of leaving Earth orbit.

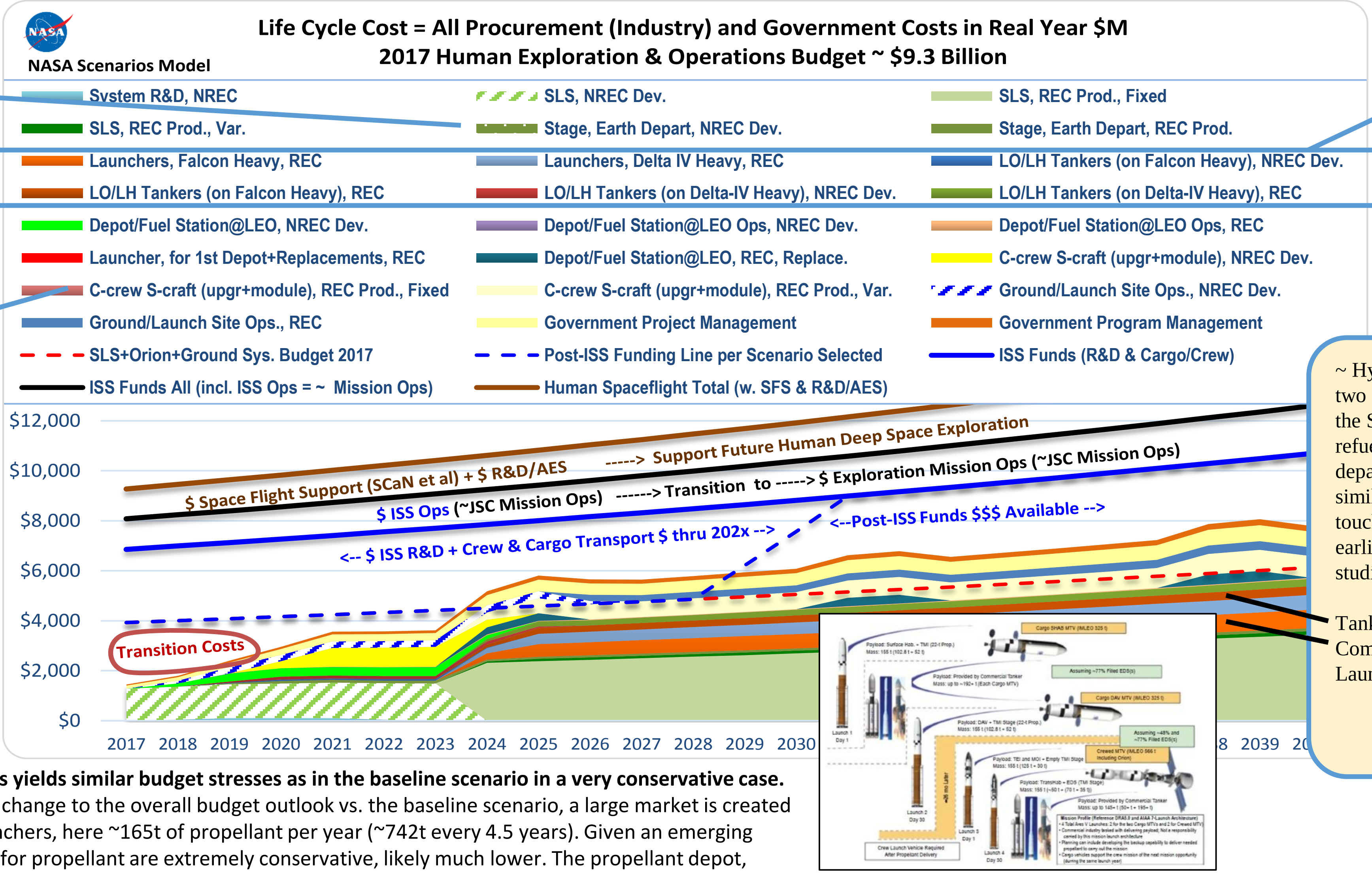
Deep space exploration as a combination of refueling and commercial launcher capabilities. The connection between any transportation capability and payloads as specific exploration elements (for example, habitation or landers) is apparent when looking at the whole as tonnage emplaced over any time by any supporting transportation system. The means, the supporting transportation system, and the ends, exploration elements leaving for deep space are by necessity fiscally linked. This scenario also emplaces a little over ~1,000t (metric tons) into low Earth orbit every 4.5 years, some of which is crew spacecraft, in this case commercial (4.5 times), and 750t of which is propellant and stages usable for going beyond low Earth orbit.

Mixing the Prior Two Scenarios → ~Baseline + Commercial Refueling

Commercial stage (deep space / departure)

Commercial crew spacecraft (deep space)

Multiple providers for competition, redundancy, and alignment of incentives

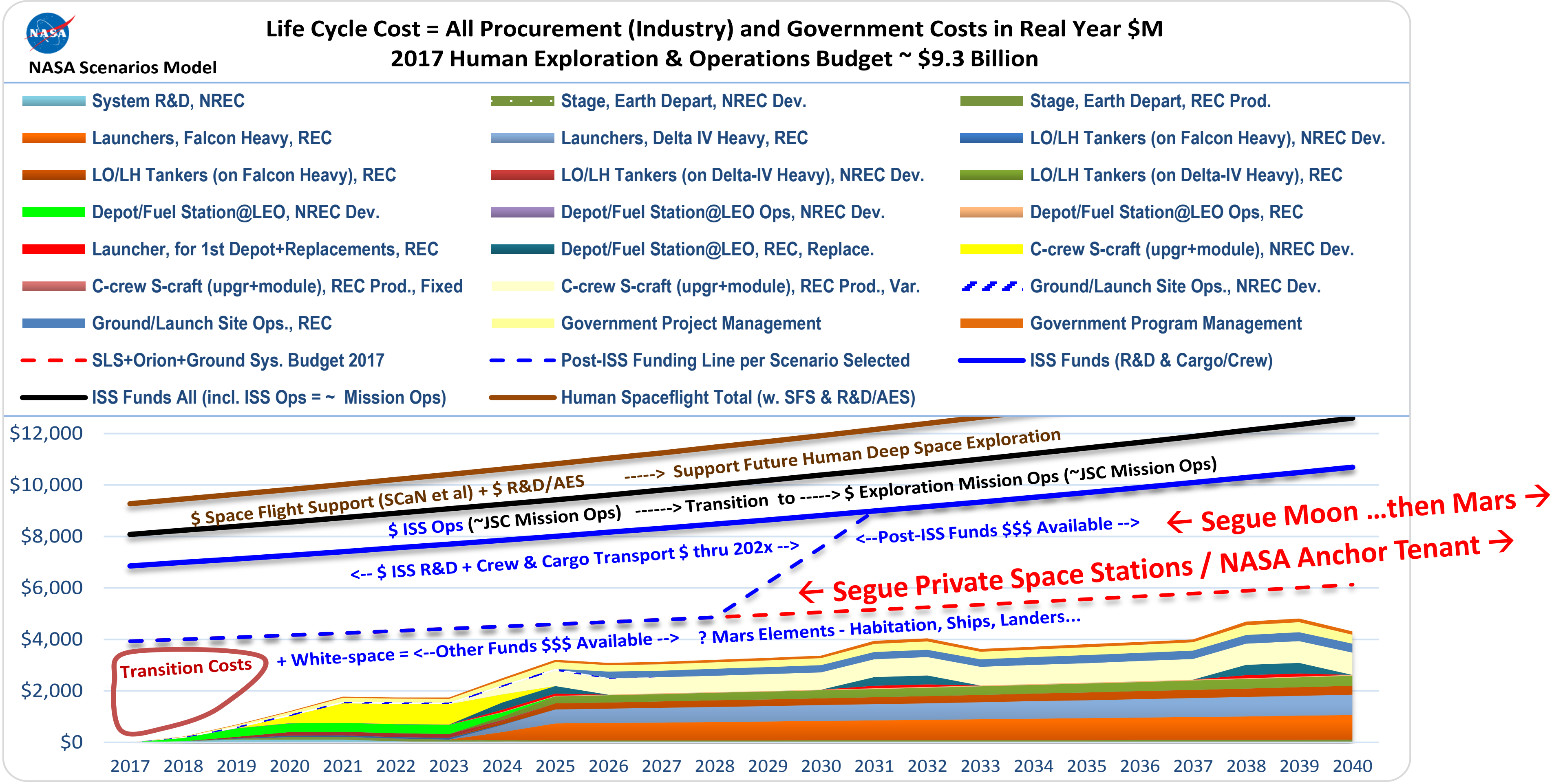


~ Hybridizing the two prior scenarios, the SLS, but with refueling of Earth departure stages, is similar to the profile touched upon in earlier NASA studies.

Tankers (propellant)
Commercial Launchers

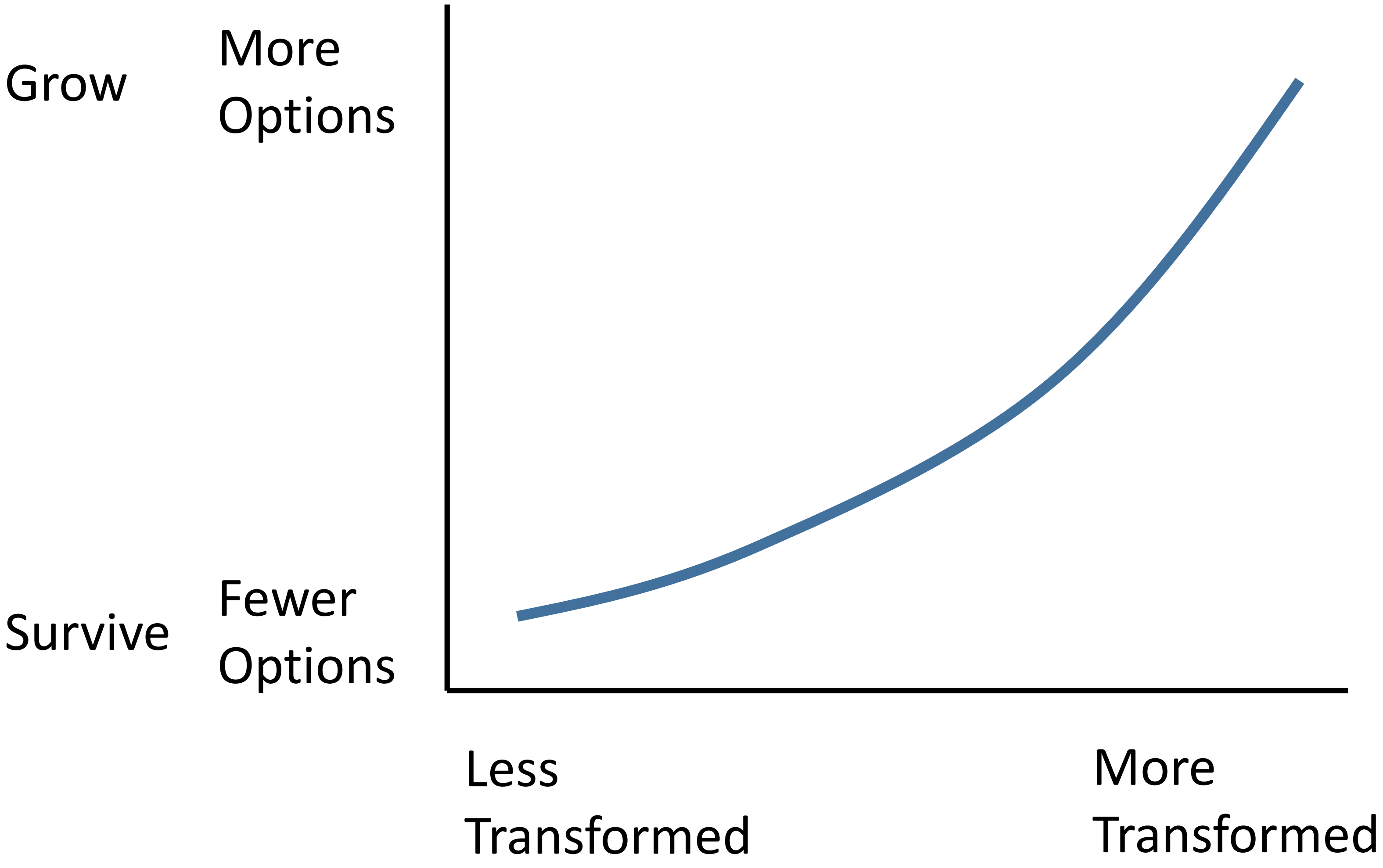
Hybridizing the prior two scenarios yields similar budget stresses as in the baseline scenario in a very conservative case. Even though there is no significant change to the overall budget outlook vs. the baseline scenario, a large market is created for commercial propellant and launchers, here ~165t of propellant per year (~742t every 4.5 years). Given an emerging competitive market the costs here for propellant are extremely conservative, likely much lower. The propellant depot, tankers, launchers and commercial spacecraft and stages (in trade for the Orion transition) could all spur other private sector uses, especially for the refueling capability, lowering costs to NASA further.

Any Scenario + White-space = Possibilities



White-space outside of the means or capability to emplace mass in orbit are funds that can be used down assorted paths. When a scenario has more funds left over in the baseline budget outlook, budget growth lines consistent with historical data since 2003, more exploration paths open up versus fewer.

Scenarios – In Review



Conclusions & Recommendations

- **Long-term life cycle cost analysis for diverse NASA human space exploration scenarios <u>is *possible, practical and useful*</u>**

Recommendation: Reconnaissance can and should look at many, different space exploration scenarios.

Best practice: Delay design decisions as long as possible.

Conclusions & Recommendations

- **Do all of our models still say ‘no’?**

No. **Some models say ‘yes’.**

Increasing space exploration ambitions squeezed under historical budget trends will cause a distribution of funding increasing NASA irrelevance.

Recommendation: We propose a steady transformation of NASA space exploration and operations funding towards more, smaller commercial / public-private partnerships, favoring those with strong non-government business cases.

Acknowledgements

The author gratefully acknowledges all the team members in the 2011 propellant depot study, led by Charles Miller, Doug Stanley and Alan Wilhite. I created the initial budget scenario model for this study leading directly to the accumulation and organization of historical data, cost estimates for new systems based on the data, and the NASA Scenario Model in use today.

The author also gratefully acknowledges all the team members in subsequent studies, the Evolvable Lunar Architecture (ELA), study, the Small Habitat Commonality Assessment (NASA internal), and the Ultra-Low Cost Access to Space (ULCATS), study lead by the Air Force. All of these studies and analysis contributed to maturing the quantitative life cycle cost data, model, methods and results in the work here.

Questions?